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ABSTRACT

A project to help vocational-technical teachers in the development and experimental analysis of self-instructional programs is presented. The emphasis in developing the program was on maximizing effectiveness and efficiency of program-learner interaction as measured by criterion items. These items emphasized cognitive content dealing with the knowledge, application, comprehension, and analysis levels. The criterion items also included manipulative content, emphasizing the graphic solution of kinematics problems. Relevant technical literature was reviewed, and technical experts consulted. The analytical methods and guidelines used to determine program content, to discover strengths and weaknesses, and to determine the effectiveness and efficiency of the program have proven to be effective. Conclusions include: (1) Content for self-instructional programs can be determined by identifying a domain of criterion items and selecting those items appropriate for a specified target population; and (2) The inclusion of randomly selected test items in the self-instructional program indicates to the student what is expected of him in the manner of his response to terminal criterion items. (CK)

THE DEVELOPMENT AND EXPERIMENTAL ANALYSIS OF A SELF-INSTRUCTIONAL PROGRAM IN GRAPHICAL KINEMATICS

Presented
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THE DEVELOPMENT AND EXPERIMENTAL ANALYSIS OF A SELF-INSTRUCTIONAL PROGRAM IN GRAPHICAL KINEMATICS

Problem

The general objective of this project was to help vocational-technical teachers in the development and experimental analysis of self-instructional programs. The specific objective of the project was to develop a self-instructional program and to verify its effectiveness and efficiency. In order to meet this specific objective, the project developer identified a number of enabling objectives. They were to: (1) determine appropriate subject matter content for a program in the area of graphical kinematics; (2) find effective methods for the development of a program by the manipulation of independent and dependent variables; (3) develop analytical procedures for the identification and improvement of inadequate and ineffective portions of a program; and (4) develop empirical guidelines for writing and evaluating programs of instruction.

Significance of the Problem

An important objective of vocational-technical education has been the improvement of instruction. The need for work in this area becomes very apparent as we study professional journals and note the increase in subject matter content without an additional increase in time allotted. Howe [5] observed this development when he wrote:

> For most of us, the time allotted for teaching [engineering] graphics has been gradually but materially reduced, as the many other educational essentials have been worked into our curriculums. To meet the changing conditions, more efficient methods for teaching the most carefully selected materials, in strictly limited amount, is replacing our former well-founded but more time consuming procedures. Thus we continually search for the effective means to maintain our standards and include the new ideas which are constantly appearing [5, p.22].

Many times students do not have the opportunity to see or hear well planned presentations by teachers. Class size limitations and the contact hours assigned to each instructor prevent contact of many students with the outstanding instructor in many cases.

Self-instructional programs, however, can increase the teacher's personal contact with the students. Teachers typically cannot deal adequately with large heterogeneous classes of students. Many students are often penalized by a lack of systematic reinforcement and active involvement with subject matter. Deterline [2] contended that:

> The students at the extreme upper and lower ends of the continuum of learning aptitude are usually additionally penalized because of the difference between the pace set by the teacher for the class and the rate of subject matter consideration that

would be best for each individual student. The self-paced feature of auto-instruction (each student proceeding at his own rate) can at least partly eliminate the problem of the slower and faster learners who cannot adequately be taught by presentations designed for, and aimed more directly at the middle of the group [2, p.74].

Various self-instructional programs could be made available to students who may have difficulty understanding or who were absent for the initial presentation. Other instructors could avail themselves of various prepared self-instructional programs for use in their classes. Substitute instructors could maintain continuity in their progress toward the course objectives.

A need now exists for studies to be conducted dealing with an experimental development and analysis of self-instructional programs which should require empirical evidence as to program effectiveness.

Lumsdaine [6] is convinced that:

> ...most existing programs afford only a rough approximation of the potentiality for control over learning which could, in principle, realize a goal of assured mastery for all qualified students ... Even casual inspection of a sample of programs suggests a tendency merely to follow superficially the general format implied by one programming rationale or another, while meeting neither the theoretical assumptions or empirical characteristics that are supposed to be exemplified. In addition to lack of adequate tryout and revision, many other apparent weaknesses are to be seen in examining the existing programs, including inadequate analysis of subject matter content and inept use of what seem to be the more promising techniques of programming [6, pp.271-2].

Self-instructional programs are to be ideally developed within the context of a laboratory experiment. Hively [3] listed basic methodological problems involved in laboratory experimentation. They are:

> (1) the problems of recording dependent variables (2) the problem of replicating independent variables from one experiment to the next, and (3) the problem on controlling other conditions which might affect the system which is being studied.
>
> . . . .
>
> In general, the experimenter's problem is to seek out and demonstrate orderly and reliable effects of his set of independent variables upon his set of dependent variables. To the extent that he finds them he has laid the groundwork for an experimental science of instruction [3, pp.1-5].

All of these considerations served as the basic rationale for the carrying out of the project.

Procedure

The project was developmental in nature in that the methods and procedures for developing a self-instructional program in graphical kinematics were studied and reported on from the initial criterion item specification to the final determination of the program's effectiveness and efficiency. Figure 1 illustrates the

systems approach used in developing the self-instructional program.

In developing the self-instructional program, the emphasis was on maximizing effectiveness and efficiency of program-learner interaction as measured by criterion items. The criterion items emphasized cognitive content dealing with the knowledge, application, comprehension, and analysis levels. The criterion items also included manipulative content, emphasizing the graphic solution of kinematics problems.

During the project an attempt was made to define an exhaustive list of criterion items for the unit taught. From this list of criterion items, a sample was selected for use in constructing the self-instruction program and the criterion test.

The terminal criterion behavior was a statement of a teaching objective in terms which allowed the existence of the behavior to be tested empirically. Empirical testing yielded information which allowed the self-instructional program to be improved and revised. The specification and analysis of terminal behaviors was a major activity in the preparation of the self-instruction program.

In order to accomplish the first step, the relevant technical literature was reviewed and a number of educational and technical experts were consulted in order for the project developer to master the subject matter. This aspect of the project has been illustrated as Event III in Figure 1.

The terminal criterion behavior desired upon satisfactorily completing all the frames in the self-instructional program booklet was established as the 100 percent ability of the reader to: (1) Recognize a Peaucellier's mechanism; (2) recognize a modified Peaucellier's mechanism; (3) recognize an inverted Peaucellier's mechanism; (4) indicate selected link ratios required in order to have a Peaucellier's mechanism; (5) state which links in a Peaucellier's mechanism, a modified Peaucellier's mechanism, and an inverted Peaucellier's mechanism have linear or angular motion; (6) state which linkage ratios cause point path curvature in a modified Peaucellier's mechanism; (7) indicate selected point relationships as motion is introduced into a Peaucellier's mechanism, a modified Peaucellier's mechanism, and an inverted Peaucellier's mechanism; and (8) graphically analyze a Peaucellier's mechanism, or a modified Peaucellier's mechanism or an inverted Peaucellier's mechanism.

The Target Population

At the time the project developer was establishing the required terminal behavior, consideration had to be given to identifying the target population. This is illustrated as Event II in Figure 1. It was emphasized in the literature that the development of a valid training and learning system requires the specification and control of target populations. The specifications should cover more than just the general psychological and intellectual characteristics of the student. The prerequisites should be listed and spelled out in behavioral terms as shown in Figure 2, Items (P1)-(P7). Better specification of the target population, with pretesting to insure the existence of prerequisite behavior, should yield much more efficient educational programs. The population for the project consisted of student groups enrolled in various post-secondary design and drafting courses.

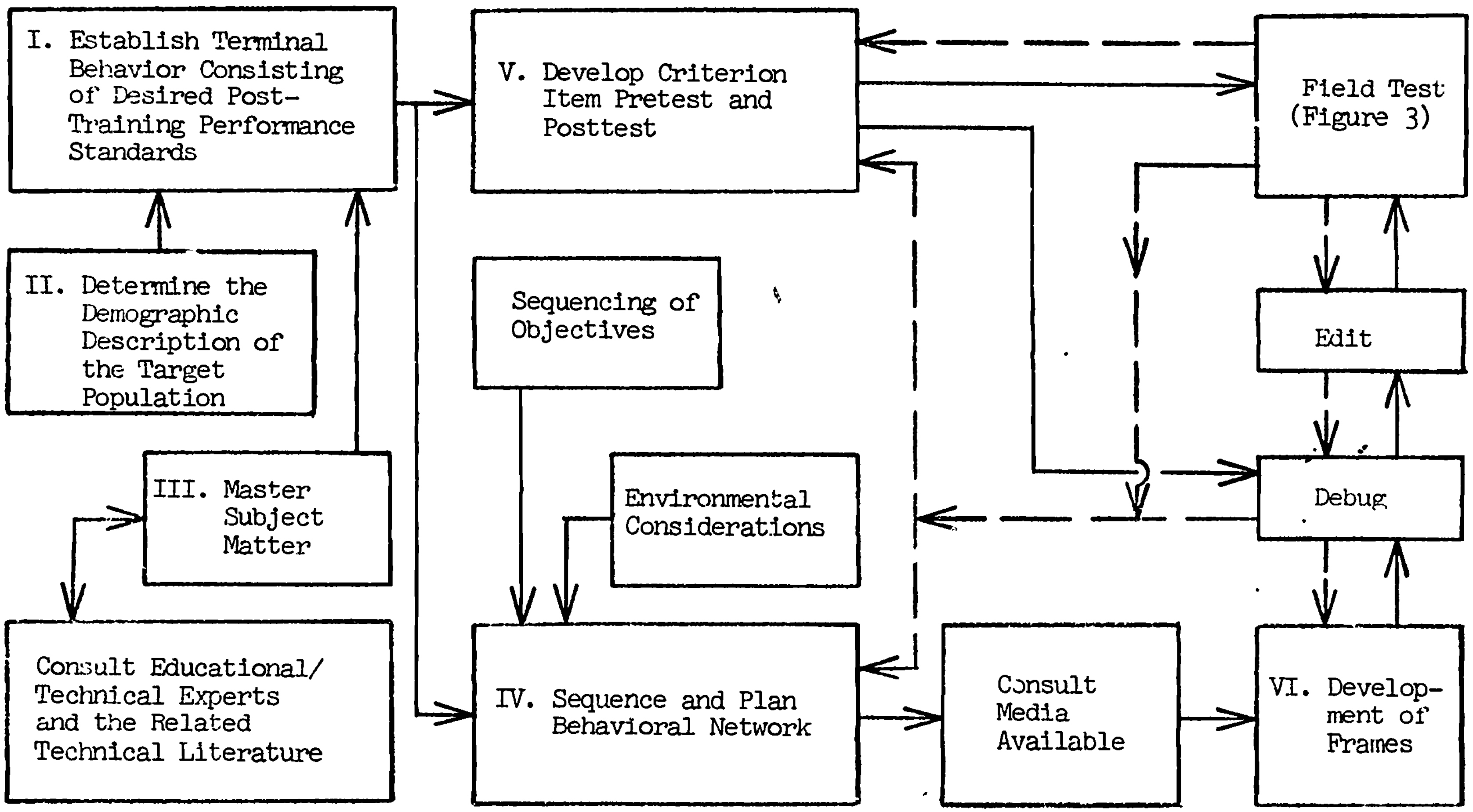

FIGURE 1

A SYSTEMS APPROACH TO DEVELOPING A SELF-INSTRUCTIONAL PROGRAM

Sequence of the Behavior Network

Event IV as shown in Figure 1 represents the arrangement of behavioral objectives from which the self-instructional program was developed. Figure 2 illustrates a schematic diagram showing the realtionships of the elements in the hierarchy of graphical kinematic objectives for Peaucellier's mechanism displacement. The formal structure of the behavioral network served both as a foundation and a practical constraint to the self-instructional program developer. The development of the behavioral network required the establishment of terminal criterion behavior, mastering of the subject matter, and determination of the target population.

The prerequisite criterion item coding key follows (selected examples only):

(P1) This item consisted of the demographic description of the target population. The population had completed a basic course in drafting or engineering drawing. This single item assumed items (P2)-(P7).

.
.
.

(P3) Make linear measurements within 1/50th part of an inch utilizing a scale with inches divided into decimal parts;

.
.
.

(P6) Use a protractor to measure angular displacements to within an accuracy of fifteen minutes; and

(P7) Develop basic geometric constructions in the transfer of angles and lines.

The intermediate behavioral criterion item coding key appears as follows:

(8) Identifying kinematic forms;

.
.
.

(32) Indicate which linkage ratios cause straight-line point path movement in an inverted Peaucellier's mechanism.

The terminal behavioral criterion item coding key is as follows:

(T33) Indicate selected linkage point relationships as motion is introduced into the mechanism;

.
.
.

(T42) Graphically analyze an inverted Peaucellier's mechanism.

The behavioral planning network took into account not only behavior itself, but also the conditions under which the behavior occurred. As a result, the conditions under which the student received all program materials were judged to be similar. The environmental factors were those for typical college drafting classroom conditions. These conditions tend to simulate actual working environments in design and drafting occupations.

After the behavioral planning network was established, the project developer proceeded in the development and writing of the criterion test instruments and the program frames.

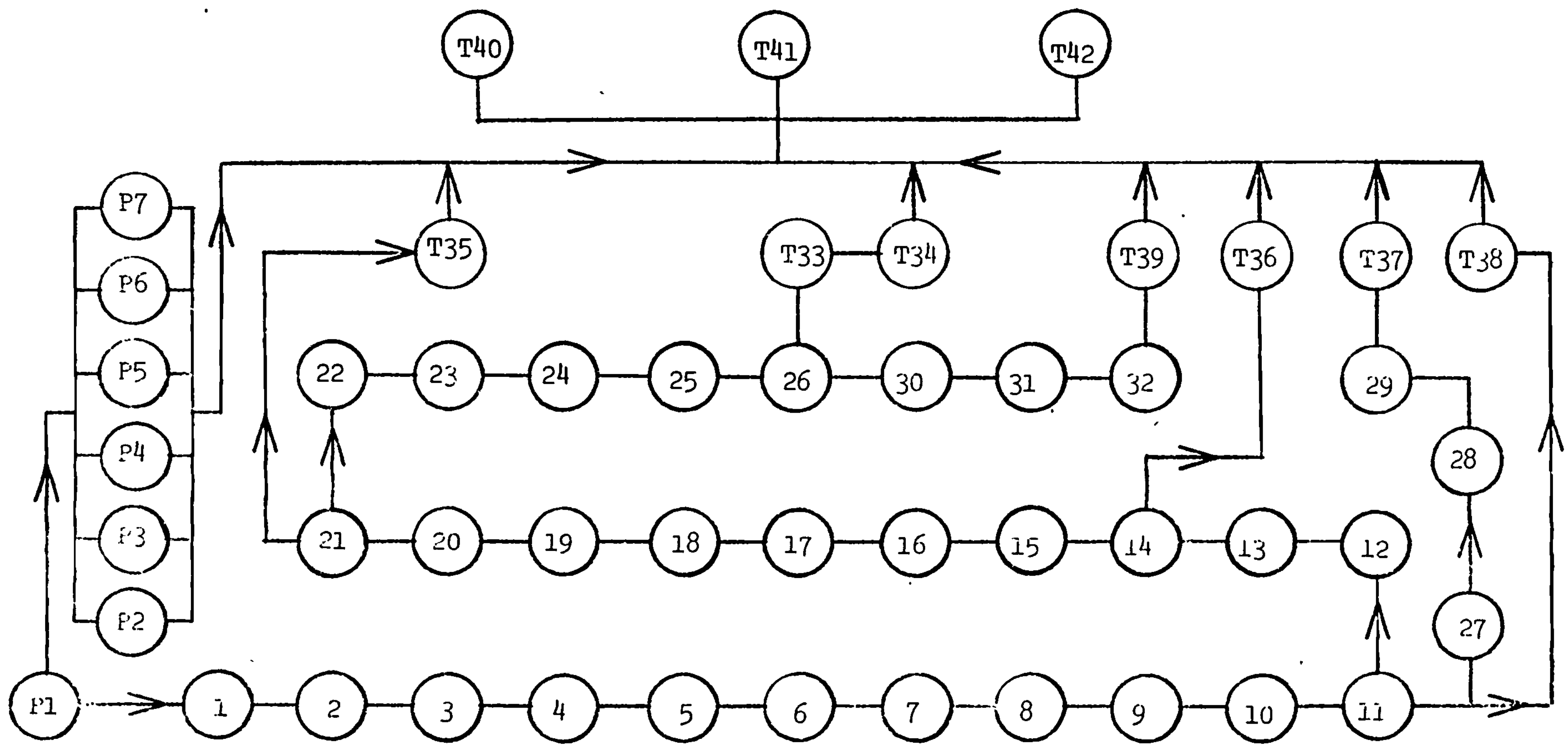

FIGURE 2

SEQUENCE OF BEHAVIORAL NETWORK

Development of the Criterion Test Instruments

The development of a comprehensive criterion test was essential and has been shown as Event V in Figure 1. A criterion test always incorporates a sufficient statement of terminal items, intermediate, and often prerequisite items. The development of partial tests for debugging purposes was required in addition to the development of the final criterion test. All the technology and caution of test construction was required.

There were no applicable standardized tests for measuring the ability to analyze the selected graphical kinematic tasks. The students were required to identify selected mechanism characteristics and to produce graphical solutions in meeting the requirements of the criterion behavior.

The project developer considered factors such as: (1) content validity; (2) reliability; (3) objectivity; (4) discrimination; (5) comprehensiveness; and (5) ease of administration and scoring.

Development of Frames

The program variation that was used in developing the project was determined by the criterion performance requirements.

Knowledge, comprehension, application and the analysis of graphical kinematics concepts require verbal behavioral outcomes for practical use in explaining the mechanism and in making graphical constructions. Completion and constructed responses approximated most closely the desired behavioral outcomes. Event VI, Figure 1, illustrates this relationship to the total developmental process.

The self-instruction prc variation selected was the linear type because of the desire for error response and the ease of diagnosing possible sources of misunderstanding by the student. It could be best designed to cover the necessary material in the limited time available.

The self-instructional program format selected was booklet form because of the desire for replication and because of its practical and economic characteristics. The booklet had only a single stimulus unit, followed by a completion or constructed response item on each page. The frames were numbered sequentially.

The efficient and successful development and debugging of the self-instructional program materials required field testing in the form of an experimental design used by the project developer for maximizing the effectiveness and efficiency of the self-instructional program. In the illustration an "X" signifies that the group was exposed to the self-instructional program and and "O" represents an observation or measurement. The progression of events proceeds from left to right.

Field Testing Experimental Design

Preliminary development and experimentation was accomplished by use of a pilot study. The pilot study consisted of responses from three subjects and has been presented as Group I in Figure 3.

Group II consisted of students enrolled in drafting, during the fall quarter 1970, in the Department of Industrial Education at the University of Minnesota, Minneapolis, Minnesota. Group III was comprised of students enrolled in mechanical drafting at Normandale State Junior College, Bloomington, Minnesota.

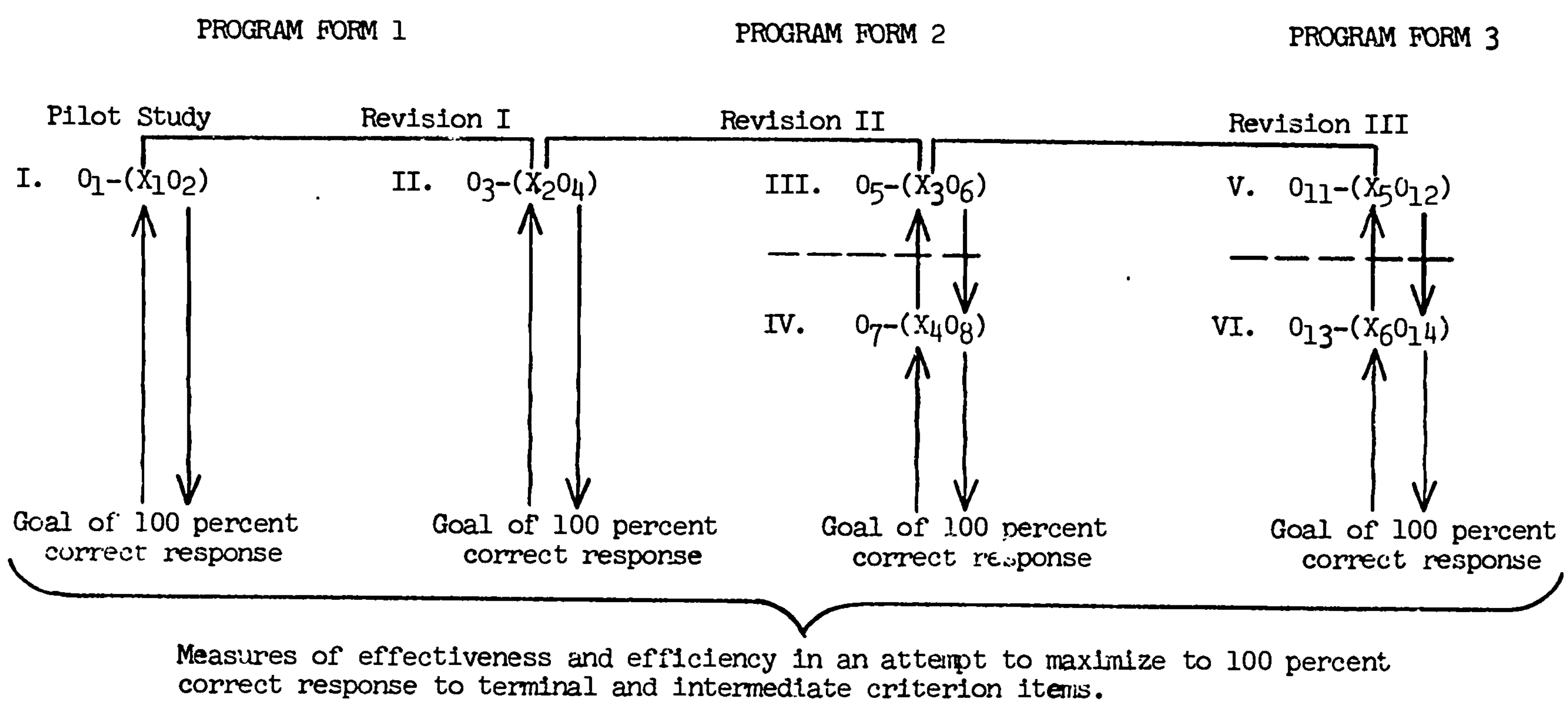

FIGURE 3

FIELD TESTING EXPERIMENTAL DESIGN

Group IV consisted of students enrolled in mechanical drafting at Willmar Vocational-Technical School, Willmar, Minnesota. Groups V and VI consisted of students enrolled in two descriptive geometry classes at Stout State University, Menomonie, Wisconsin.

The students in each group received pretests, the self-instructional program, and a posttest as an integrated part of the respective course requirements. The reader should keep in mind that Group VI did not receive the self-instructional program pretest, but received only the Space Relations Test and the Mechanical Comprehension Test. The deletion of the self-instructional program pretest was due to the inability to schedule the same time period and length of time for Group VI that was available to Groups II through V. The experimental treatment of the self-instructional program and the posttest were administered during the last two weeks of each course, while the pretests were administered approximately two days before the students received the program treatment. The pretest and posttest consisted of identical, but rearranged criterion items.

In an attempt at complete optimization, the response errors on criterion items and the time students spend in self-instruction are minimized. The degree of retention after a specified period of time, as measured by errors on criterion items should also be considered.

Hively [4] suggested the use of a person-by-item matrix, as shown in Figure 4, for use in estimating the easiness of a single criterion item.

PERSONS	ITEM 1
1	1
2	0
.	.
.	.
.	.
p	X_p
	ΣX_p

FIGURE 4

PERSON-BY-ITEM MATRIX

"In this matrix, person p receives a score X_p which equals 1 if he answers correctly and 0 if he answers incorrectly" [4, p.8]. The easiness (M_1) of the specific item, or unit, can be calculated by $M_1 = \frac{\Sigma X_p}{p}$.

In estimating performance over a set of items, the data may be summarized as in Figure 5.

The proportion of items answered correctly (M_p) by person p, can be determined by $M_p = \frac{\Sigma X_{pi}}{i}$, and the mean for the entire item form (M_f) can be calculated by $M_f = \frac{\Sigma\Sigma_{pi}}{pi}$. In the development and revision of a self-instructional program, the comparison of M_i's, M_p's and M_f's for different versions should provide clues to the effectiveness of the various program forms.

ITEM FORM

PERSONS	ITEMS 1	2	i	
1	1	1	X_{1i}	M_1
2	0	0	X_{2i}	M_2
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
p	Xp1	Xp2	Xpi	M_p
	M_1	M_2	M_i	M_r

FIGURE 5

PERSON-BY-ITEM MATRIX

The person-by-item matrix may also include a doubt distribution.

Units / Students	U_1	U_2	U_3	U_4	U_5	U_6	...	U_n
S_1			E?		?		...	
S_2	E?	E	E		?		...	?
S_3			E?				...	
S_4			E		?		...	
S_5			E?				...	
S_6							...	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
S_n			E		?		...	

Reading Key: E error ? lack of understanding

In this simple hypothetical example we find a clear error concentration on Unit 3 on the one hand (for almost all subjects) and for Subject 2 on the other hand (for almost all units). We also find a relatively large number of question marks for unit 5 in spite of the fact that this unit has not attracted any errors at all. These kinds of information are evidently better starting-points for revision attempts than overall error percentages for total programs...[1, p.120].

FIGURE 6

TYPICAL STRUCTURE OF A SIMPLE SURVEY TABLE
("ERROR-AND-DOUBT DISTRIBUTION")

The student's terminal behavior should be the final criterion of the effectiveness of a self-instructional unit. If students can reach acceptable levels of understanding within a reasonable time span, the program can be termed efficient.

The Computational Procedures and Defining the Population

To aid in making a valid analysis of the students' responses to the program and posttest, basic information was needed pertaining to the equivalency of the selected groups. If Groups II, III, IV, V and VI were found to generally belong to the same population, a more valid comparison of program and posttest M_1 and M_f coefficients could be made for each revision of the self-instructional program materials. Scores earned on: (1) the Graphical Kinematics Pretest; (2) the Bennett Mechanical Comprehension Test; and (3) the Space Relation Test (DAT) were used to compare the groups. Graphical kinematics pretest completion times and the number of weeks of drafting training were also used to compare the groups in order to determine whether the participants from the four locations were of the same population. In order to compare the groups certain appropriate statistical tests were utilized.

One-way classification analysis of variance techniques as suggested by Popham [7] were used to determine the significance of mean differences between the groups simultaneously, for each of the five measures previously specified. Two basic assumptions of the one-way analysis of variance were that the subgroups be randomly drawn from a normally distributed target population and that the variance within these subgroups be homogeneous.

Popham [7] indicated that when taking a theoretical viewpoint the assumptions underlying analysis of variance must be rigorously fulfilled. This researcher goes on to say that there is evidence that even if fairly significant departures from strict theoretical assumptions may exist, analysis of variance is sufficiently "robust" so that it will give results which can be meaningfully interpreted.

Where analysis of variance produced a significant F ratio indicating that a significant mean difference existed between groups, the project developer utilized the analysis method proposed by Scheffé. This method, as presented by Walker and Lev [8, pp.303-6], leads to a confidence interval for a contrast among population means. The confidence limits for the contrast $\mu_i - \mu_1$ are:

$$\text{Upper limit:} \quad (\overline{X}_i - \overline{X}_j) + \sqrt{(k-1)F_c(MS_W)\left(\frac{1}{n_i} + \frac{1}{n_j}\right)}$$

$$\text{Lower limit:} \quad (\overline{X}_i - \overline{X}_j) - \sqrt{(k-1)F_c(MS_W)\left(\frac{1}{n_i} + \frac{1}{n_j}\right)}$$

when: $(\overline{X}_i - \overline{X}_j)$ = mean difference between contrasted groups;

k = number of groups;

F_c = c th percentile for (k-1) and (n-1) degrees of freedom obtained from the prior analysis of variance;

MS_W = error mean square obtained from the prior analysis of variance; and

n_i and n_j = number in each respective contrasted group.

In applying these formulas, if one limit was found to be positive and the other negative, 0 was a possible value of $\mu_i - \mu_j$, so the observed difference $(\bar{X}_i - \bar{X}_j)$ was nonsignificant. As a result, it was concluded that the population means of the two contrasted groups did not differ significantly from each other.

The project developer then proceeded to test for homogeneity of variance among the subgroups. Popham [7] and Walker and Lev [8] indicate that Bartlett's test can be used to determine homogeneity of variance among subgroups of different sample sizes. Bartlett's statistic (B) with a critical region $B > \chi^2_{\alpha:k-1}$ is:

$$B = \frac{2.3026}{C}\left[\sum_{i=1}^{k}(n_i - 1)\log S_W^2 - \sum_{i=1}^{k}(n_i - 1)\log s_i^2\right]$$

when: S_W^2 is the pooled variance of the k sample variances

and

$$S_W^2 = \frac{\sum_{i=1}^{k}(n_i - 1)\, s_i^2}{\sum_{i=1}^{k}(n_i - 1)}$$ and when:

$$C = 1 + \frac{1}{3(k-1)}\left[\sum_{i=1}^{k}\frac{1}{n_i - 1} - \frac{1}{\sum_{i=1}^{k}(n_i - 1)}\right]$$

If B was less than the critical region set up for χ^2 there was statistical evidence that the population variances were equal. By use of this statistical test the project developer was able to test for a basic assumption underlying the analysis of variance technique.

Graphical Kinematics Pretest

The data used in computing the various statistical tests are shown in Table 1.

TABLE 1

DATA BASED ON GRAPHICAL KINEMATICS PRETEST

Group Location	N	$\bar{X}$	s^2
Group II	22	2.27	1.16
Group III	14	1.14	3.36
Group IV	10	1.90	.77
Group V	18	1.33	6.56
Group VI (Did not participate in graphical kinematics pretest)			

A summary of the statistics used in the analysis of variance for the graphical kinematics pretest appears in Table 2.

TABLE 2

ANALYSIS OF VARIANCE FOR GRAPHICAL KINEMATICS PRETEST

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.95}$
Between groups	12.52	3	4.17	1.34	2.76
Within groups	187.48	60	3.12		
TOTAL	200.00	63			

The critical region at the .05 level of significance and with the appropriate degrees of freedom was $F>2.76$. The calculated F value indicated that there was no significant difference among the means of the four groups.

In testing for homogeneity of variances for the groups, the project developer utilized Bartlett's statistic. The rejection interval for the graphical kinematics pretest was $\chi^2>\chi^2_{3(.95)}$. The tabulated critical region was $\chi^2>7.815$ and the calculated value of B was 18.97 indicating that the group variances were not homogeneous.

Space Relations Test (DAT)

The data used in calculating the various statistical tests based on the Space Relations Test (DAT) are shown in Table 3.

TABLE 3

DATA BASED ON SPACE RELATIONS TEST (DAT)

Group Location	N	$\bar{X}$	s^2
Group II	22	77.68	139.80
Group III	14	74.43	381.80
Group IV	10	81.20	122.40
Group V	18	77.17	238.45
Group VI	21	77.63	219.29

A summary of the statistics used in the analysis of variance for the Space Relations Test (DAT) appears in Table 4.

TABLE 4

ANALYSIS OF VARIANCE FOR SPACE RELATIONS TEST (DAT)

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F	$F_{.95}$
Between groups	520.86	4	130.21	9.28	2.48
Within groups	1,122.25	80	14.03		
TOTAL	1,643.11	84			

The critical region at the .05 level of significance and with the appropriate degrees of freedom was F>2.48. The calculated F value indicated that there was a significant difference among the means of the five groups.

In order to determine which sample means of the groups tested were significantly different from each other, the project developer arranged the groups in order of increasing magnitude. All possible differences between pairs were then determined and presented in Table 5.

Confidence intervals were constructed for all possible unweighted contrasts between pairs by use of Scheffé's method. The confidence limits for Groups III and IV were found to be $+1.89 < \mu_4 - \mu_3 < +11.65$. All other confidence limits included 0 as a possible value of $\mu_i - \mu_j$. The project developer concluded that the mean scores for Groups IV and III differed significantly from each other.

TABLE 5

DIFFERENCES BETWEEN PAIRS FOR SPACE RELATIONS TEST (DAT)

Group		GROUP MEANS ($\overline{X}$) III	V	VI	II	IV
	$\overline{X}$ =	74.43	77.17	77.63	77.68	81.20
III		—	2.74	3.20	3.25	6.77*
V			—	.46	.51	4.03
VI				—	.05	3.57
II					—	3.52
IV						—

*Significant

In testing for homogeneity of variances for the groups, the project developer obtained a B value of 5.46.. The tabulated critical region was found to be $\chi^2 > 9.488$ which provided statistical evidence that the group variances were homogeoeous at the

.05 level of significance.

Graphical Kinematics Posttest

Upon completion of the graphical kinematics self-instruction program, the participants were asked to take a posttest dealing with graphical concepts and constructions. The average scores and group variances are shown in Table 6.

TABLE 6

DATA BASED ON GRAPHICAL KINEMATICS POSTTEST

Group Location	N	$\bar{X}$	s^2
Group II	22	9.00	6.38
Group III	13*	10.31	4.89
Group IV	10	10.90	5.66
Group V	18	11.61	6.13
Group VI	21	11.91	1.19

*One student did not participate in posttest (pretest N=14)

The project developer was encouraged by the steady increase in the average score of each group. The groups' posttest variances tended to decrease slightly, while at the same time their average posttest scores steadily increased. This was the case for all groups except Group V. The pretest variance for Group V was the largest for those groups receiving the pretest. The posttest variances tended to increase from what the pretest variances were for each group receiving both tests. This increase did not occur for Group V as the pretest variance was slightly larger than the posttest variance. The groups' posttest variances simply tended to indicate the degree of individual differences within each group.

When the data presented in Table 1 and Table 6 were combined, the average pretest to posttest gain and the group gain variances were found. Table 7 illustrates these gains.

TABLE 7

DATA BASED ON GRAPHICAL KINEMATICS PRETEST TO POSTTEST GAIN

Group Location	N	$\bar{X}$	s^2
Group II	22	6.73	7.26
Group III	13*	9.08	4.41
Group IV	10	9.00	4.54
Group V	18	10.11	13.63
Group VI (Did not participate in graphical kinematics pretest)			

*One student did not participate in posttest (pretest N=14)

The data presented illustrates a steady average gain in scores for each revision of the self-instructional program. Even though the pretest to posttest average gain for Group V was the greatest, the pretest to posttest gain variance was approximately three times the gain variance for the previous revision. The pretest to posttest gain variances tended to indicate the amount of individual differences for each group.

The average completion times in minutes for the posttest are shown in Table 8. The average times remained relatively constant, while the time variances for the posttest indicated decreasing values.

TABLE 8

DATA BASED ON GRAPHICAL KINEMATIC POSTTEST TIMES

Group Location	N	$\overline{X}$	s^2
Group II	22	15.68	31.46
Group III	13*	14.53	30.10
Group IV	10	14.10	10.29
Group V	18	15.06	20.0[illegible]
Group VI	21	14.29	16.41

*One student did not participate in posttest (pretest N=14)

Comparison of Item M_i's, M_f's and Doubt Distributions

During the development and experimental analysis of the self-instructional program, the project developer was required to collect certain data. This data provided the basis for any revision of the program format, sequence and content.

Tables 9, 10 and 11 summarize completely the degrees of easiness for each criterion item (M_i's) from the pretest and posttest. The average times in minutes for the constructed response, Item 1 and the total average times in minutes for criterion Items 2 through 13 are also given for each program revision. The degrees of easiness for each test (M_f's) indicate any change in performance for each participant group. The degree of doubt for each item and for each group is presented as a doubt distribution (?).

In analyzing the posttest M_i values for Revision I, Table 9, which was administered to Group II, the project developer determined that the sequence leading to criterion Items 1, 2, 3, 4, 5, 6, 7, 8, 10 and 13 required revision in order to increase their effectiveness. The posttest M_i values for Revision II, Table 10, Groups III and IV indicated that the sequences leading to Items 1, 2, 3, 4, 6, 8 and 13 required still further revision. Items 3, 4 and 8 of Revision III, Table 11, Groups V and VI still require additional program sequence revision.

The doubt distribution for the pretest and posttest included only doubt responses (?) for those items which were answered correctly with doubt. Those items that were answered incorrectly with doubt were not included in the distribution. The degree of doubt tended to decrease for each program revision. The doubt decreased from pretest to posttest except for Group IV. The relatively high doubt distributions tended to correspond to the low M_i values.

TABLE 9

DATA BASED ON GRAPHICAL KINEMATICS PRETEST AND POSTTEST INCLUDING ITEM M_I's, DOUBT DISTRIBUTIONS, $\overline{X}$ ITEM TIMES, TEST M_f's AND PERSENTAGE GAINS FOR REVISION I

Group Location	Test	Item M_I's and $\overline{X}$ Item Times															Doubt	Test	%
		1	$\overline{X}^1$ Time	2	3	4	5	6	7	8	9	10	11	12	13	$\overline{X}^2$ Time	(?)	M_f	Gain
Group II	Pre	.27 1?	11.00	.00	.00	.00	.00	.00	.41 3?	.05	.27 3?	.05	.77 2?	.14 1?	.32 1?	13.27	11	.13	57.10
	Post	.50	8.73	.68 2?	.59 2?	.27 2?	.64	.77 1?	.86	.18 1?	.95	.86	.91	.95	.82	6.95	8	.61	

$\overline{X}^1$ = Average time for Item 1 response

$\overline{X}^2$ = Total average time for Items 2 through 13 responses

TABLE 10

DATA BASED ON GRAPHICAL KINEMATICS PRETEST AND POSTTEST INCLUDING ITEM M_1's, DOUBT DISTRIBUTIONS, $\overline{X}$ ITEM TIMES, TEST M_f's AND PERCENTAGE GAINS FOR REVISION II

Group Location	Test	Item M_1's and Average $\overline{X}$ Item Times														Doubt (?)	Test M_f	% Gain
		1	$\overline{X}^1$ Time	2	3	4	5	6	7	8	9	10	11	12	13	$\overline{X}^2$ Time			
Group III	Pre	.21	11.14	.00	.00	.00	.00	.00	.07 1?	.00	.14 2?	.14 2?	.29 2?	.07	.21	6.65	6	.09	69.80
	Post	.69	8.15	.77 1?	.46	.46	.92	.77	.92	.77	.77	1.00	1.00	1.00	.77	6.38	1	.79	
Group IV	Pre	.30	12.70	.00	.00	.00	.10 1?	.00	.10	.00	.30	.00	.90 1?	.20	.00	12.20	2	.15	69.20
	Post	.90	6.60	.70	.50 1?	.70 1?	.80 1?	.90	.80 1?	.70	1.00	1.00	1.00	1.00	.90	7.50	4	.84	

$\overline{X}^1$ = Average time for Item 1 response

$\overline{X}^2$ = Total average time for Items 2 through 13 responses

TABLE 11

DATA BASED ON GRAPHICAL KINEMATICS PRETEST AND POSTTEST INCLUDING ITEM M_1's, DOUBT DISTRIBUTIONS, $\overline{X}$ ITEM TIMES, TEST M_f's AND PERCENTAGE GAINS FOR REVISION III

Group Location	Test	Item M_1's and Average $\overline{X}$ Item Times															Doubt	Test	%
		1	$\overline{X}^1$ Time	2	3	4	5	6	7	8	9	10	11	12	13	$\overline{X}^2$ Time	(?)	M_f	Gain
Group V	Pre	.11	8.89	.06	.06	.06	.11 1?	.06	:17 2?	.11 1?	.17 1?	.17 3?	.44 1?	.06 1?	.00	7.06	10	.12	77.80
	Post	1.00	9.16	.94 1?	.72 2?	.72	.89	.89	.89	83	1.00	.94	.94	.94	.89	5.88	3	.89	
Group VI	Pre			(Did not participate in graphical kinematics pretest)															
	Post	.81	7.67	.95	.81	.67	.90	.95	.95	.95	1.00	1.00	1.00	1.00	.90	6.62	0	.92	---

$\overline{X}^1$ = Average time for Item 1 response

$\overline{X}^2$ = Total average time for Items 2 through 13 responses

The criterion test M_f values for the three revisions steadily increased from approximately .60 to .90. These values indicate a trend towards 100 per cent program effectiveness.

The percentage gain for each program revision was calculated by dividing the total pretest to posttest gain by 13 for each individual and then determining the average percentage gain for each group. The percentage gain steadily increased for each program revision.

Program Information Density and Informational Speed

During experimentation utilizing the program materials, the project developer calculated informational density and informational speed coefficients. The values obtained are given in Table 12.

The information density coefficients (I_d) were obtained by using the following formula:

$$I_d = \frac{A_i - B_i}{D_i}$$

when:

A_i = the average error percentage of the student group on criterion problems before using the self-instructional materials;

B_i = the average error percentage of the student group on criterion problems after using the self-instructional materials; and

D_i = the number of program responses used in teaching the selected concepts.

The information speed coefficients (I_s) were computed using this formula:

$$I_s = \frac{A_i - B_i}{T_i}$$

when:

T_i = the average program time in minutes.

Fulfillment of Objectives

The self-instructional program on graphical kinematics experimentally developed and tested during this project did not reach the ultimate goal of 100 percent correct performance and, therefore, needs continued improvement as it is used for future instruction. The results indicated, however, that by utilizing the methods of content development and analysis used during the project, an effective and efficient self-instructional program can be developed. The major objective of the developmental project was basically fulfilled.

The matrix analysis techniques used for determining the strengths and weaknesses in the self-instructional program and the use of informational density and speed coefficients proved to be effective methods in analyzing students' responses to the program booklet and the criterion tests. The informational feedback from the questionnaire schedule and from individuals participating in the

TABLE 12

INFORMATIONAL DENSITY AND INFORMATIONAL SPEED COEFFICIENTS BASED ON GRAPHICAL KINEMATICS PROGRAM, PRETEST AND POSTTEST DATA

Group Location	Percent Gain (A_1-B_1)	Program Responses (D_i)	$\overline{X}$ Program Time (T_i)	Information Density (I_d)	Information Speed (I_s)
Group II	51.70	66	42.82	.78	1.21
Group III	69.80	115	53.00	.61	1.32
Group IV	69.20	115	54.00	.60	1.28
Group V	77.80	138	62.00	.56	1.25
Group VI	(Did not participate in graphical kinematics pretest)				

pilot study also proved to be of value in determining troublesome segments of the program materials.

The analytical methods and empirical guidelines used to determine program content, to discover strengths and weaknesses, and to determine the effectiveness and efficiency of the program have proven to be effective. These same methods should be able to be effectively used by teachers and educational technologists for developing self-instructional programs in other subject areas.

Conclusions

During the period that the project developer was involved with this project, certain data were gathered and organized. From this data the following conclusions were drawn:

Content for self-instructional programs can be determined by identifying a domain of criterion items and selecting those items appropriate for a specified target population. These selected criterion items must define in exact behavioral terms what the student should be able to do when he has been exposed to the program of instruction.

Programs of instruction can be constantly improved by analyzing the responses made to the program booklet and the criterion tests. This can be accomplished only if some method of coding is used to identify selected program micro sequences with the appropriate criterion items.

Items selected from a domain of criterion items were used to test the student's understanding of the subject area. This process can be used to determine both individual and group performance and also to locate inadequate program and criterion test segments.

The inclusion of randomly selected test items in the slef-instructional program indicates to the student what is expected of him in the manner of his response to terminal criterion items. Pretesting and posttesting can be accomplished by randomly selecting criterion items from the domain of criterion items. By doing this, the developer can determine the educational gain for individuals and groups.

During all phases of program development much relevant information can be obtained by recording students' comments. Many program improvements can be made by utilizing this information.

The degree of effectiveness and efficiency for a program of instruction can be determined by the matrix analysis and analytical models used during the development of this project.

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